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**CHEMICAL BIOLOGICAL CENTER**

U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

**ECBC-TR-405**

**TEST RESULTS  
OF AIR-PERMEABLE SARATOGA™ HAMMER SUIT  
TO CHALLENGE BY CHEMICAL WARFARE AGENTS**

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14. ABSTRACT Swatches from an air-permeable Tex-Shield SARATOGA™ Hammer Suit were challenged with liquid droplets of sarin (GB) and mustard (HD) using modifications of the convective permeation test procedure described in TOP 8-2-501. The cumulative mass of each agent that permeated each swatch was determined over time. The results for all swatches were used to determine a weighted-average cumulative mass for the suit. From that data, a physiologically derived breakthrough time was calculated for comparison purposes.					
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## EXECUTIVE SUMMARY

As part of the Domestic Preparedness Program, an air-permeable, charcoal impregnated SARATOGA™ Hammer Suit from Tex-Shield, Incorporated, was tested to assess its capability to protect in a chemical warfare (CW) agent environment. Swatches of material from the suit were tested for resistance to permeation by mustard (HD) and sarin (GB). From that data, the authors calculated the estimated time it would take for sufficient agent to permeate the suit to cause physiological effects in a person wearing the suit. The tests are described and the calculated breakthrough times are presented. The overall breakthrough time was >396 min for GB and 253 min for HD.

This suit was also tested to assess its ability to protect the wearer from an aerosolized threat. Human test subjects donned the suit and entered a corn oil aerosol chamber. The subjects then performed a series of exercises to stress the seals of the suit. A continuous sample was pulled from the suit and analyzed by a laser photometer to see if any corn oil aerosol had entered the suit. Of the trials tested, 93.75% had an overall protection factor (PF) > 2.0, while none had an overall PF > 5.0. All overall protection factors were between 1.9 and 3.4.

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## PREFACE

The work described in this report was authorized under the Expert Assistance (Equipment Test) Program for the U.S. Army Edgewood Chemical Biological Center (ECBC) Homeland Defense Business Unit. This work was started in July 2003 and completed in December 2003.

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# TEST RESULTS OF AIR-PERMEABLE SARATOGA™ HAMMER SUIT TO CHALLENGE BY CHEMICAL WARFARE AGENTS

## 1. INTRODUCTION

In 1996, Congress passed Public Law 104-201 (Defense Against Weapons of Mass Destruction Act of 1996), directing the Department of Defense (DoD) to assist other federal, state, and local agencies in enhancing preparedness for terrorist attacks using weapons of mass destruction. The DoD responded by forming the Domestic Preparedness Program that same year. One of the objectives of the Domestic Preparedness Program is to enhance emergency and hazardous material (HAZMAT) response to nuclear, biological, and chemical (NBC) terrorism incidents. As part of an effective response, personnel who are responding to an incident will use personal protective equipment (PPE) to protect them from exposure to chemical agents. The specific PPE that will be used by emergency responders depends upon the situation that they encounter and the PPE that the responders currently possess. In some cases, air-permeable charcoal impregnated protective suits may be used to enter a contaminated or potentially contaminated area. Air-permeable charcoal impregnated protective suits are designed to protect the wearer's skin from chemical vapor.

## 2. OBJECTIVES

This study evaluated the commercially available air-permeable, charcoal impregnated SARATOGA™ Hammer Suit to assess how well it could resist vapor permeation from liquid contamination<sup>1</sup> by chemical agents mustard (HD) and sarin (GB). This information is intended for federal, state, and local emergency and HAZMAT personnel as an aid in their evaluation (and possible modification) of current work rules regarding specific air-permeable charcoal impregnated suits currently in inventory and as an aid in future procurement of appropriate air-permeable charcoal impregnated suits. This is especially important if these personnel choose to include military chemical agent protection as a criterion for purchase. This information supplements data and information provided by the suits' manufacturers. The suits were tested as received. The effects of aging, temperature extremes, laundering, and other factors are beyond the intended scope of this test program. These tests are conducted to assess percutaneous (i.e. skin) protection<sup>2</sup> only.

## 3. TESTING AND DATA ANALYSIS

### 3.1 Testing Overview.

The air-permeable, charcoal impregnated SARATOGA™ Hammer Suit was manufactured by Tex-Shield, Incorporated (Washington, DC). The navy blue suit is a two-piece

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<sup>1</sup> Throughout this report the term permeation is used even though for some of the tests the precise mechanism of agent transfer is not determined and penetration is likely to be involved also.

<sup>2</sup> Inhalation and ocular protection are typically provided by the use of a respirator that covers the eyes, nose, and mouth.

chemical warfare protective overgarment, consisting of a hooded coat and trousers. The SARATOGA™ Hammer Suit is similar in design to the Department of Defense SARATOGA™ JSLIST overgarment. The outer shell fabric is water repellent finished, 100% Cotton ripstop. The liner is SARATOGA™ A1195, a polyester knit coated with activated carbon spherical adsorbers covered with a non-woven laminate.<sup>3</sup> The suit (lot# BL100401891) was inspected 1 April 03 and considered acceptable. Figure 1 shows the suit labels for the coat and trousers. Appendix C shows the test suit. Permeation tests of material swatches were conducted to measure the permeation of both GB and HD through the suit material swatches.

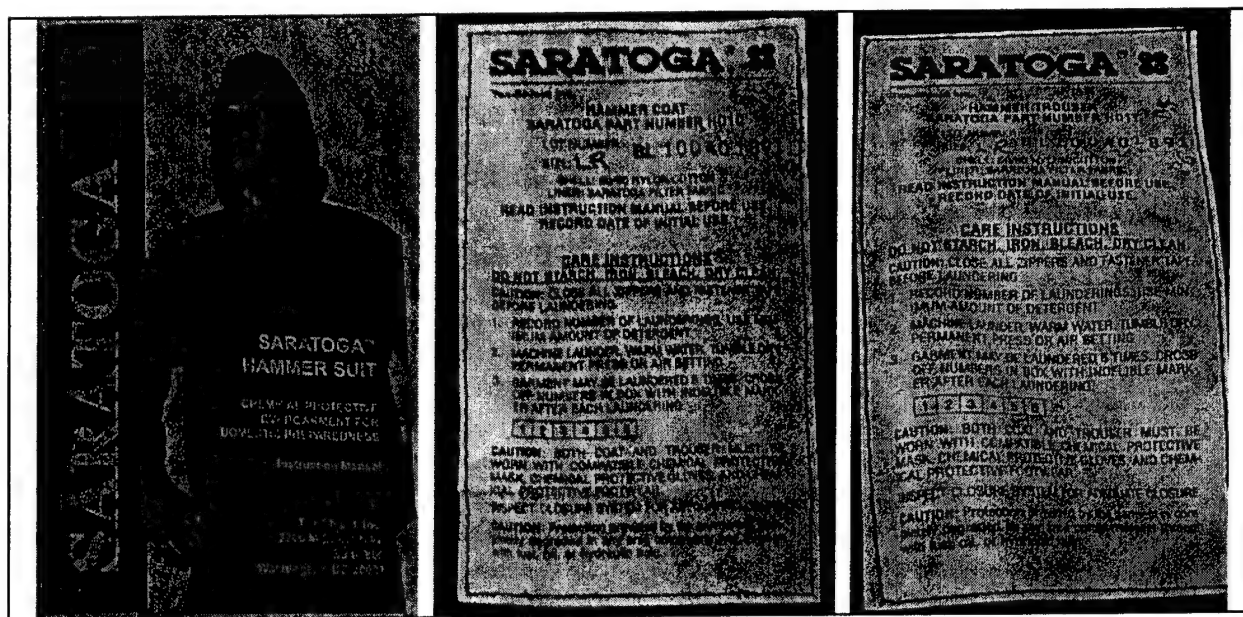


Figure 1. SARATOGA™ Hammer Suit Instruction Manual and Suit Labels

### 3.2 Liquid Challenge/Vapor Permeation Testing (Agent Swatch Testing).

This testing was conducted to measure the permeation of chemical agents GB and HD through suit swatches over a 24-hr period. The test was intended to assess how well the suit materials and seams resist agent permeation. The amount of agent applied and duration of exposure do not represent any particular threat that responders may encounter, but they do serve as a common point of reference for all test results. The Applied Test Team of the Research and Technology Directorate, Edgewood Chemical Biological Center (ECBC) performed the testing.

The suit coat and trousers were each placed in a sealable plastic bag and kept on a laboratory table for storage during testing. The swatch locations to be sampled were given in the Modified Convective Permeation Test Procedure (Appendix A). Three swatches each were taken from the chest area, thigh area, crotch area, upper arm seam, lower leg seam, and hood seam. At least one of the swatches from the crotch area included a seam. The swatches had a

<sup>3</sup> Information taken from the Saratoga™ Hammer Suit Chemical Protective Overgarment for Domestic Preparedness Instruction Manual (Tex-Shield, Inc., 2300 M Street N.W., Suite 800, Washington, DC 20037)

diameter of  $1\text{-}\frac{15}{16}\text{-in.}$  and were cut on a sample press, normally the day before testing. The swatches were mounted in test cells and placed in the test cabinet for at least an hour conditioning at 90 °F and 35% RH prior to testing; one swatch per test cell.

### 3.2.1 Liquid Challenge/Vapor Permeation Testing Procedures.

The modified convective permeation test procedure was adapted from TOP 8-2-501<sup>4</sup> and is described in Appendix A. Air permeability was determined using a Frazier Precision Instrument (#961) low-pressure air permeability machine. The minimum air permeability for use of this test procedure is  $20\text{ cm}^3/\text{min}/\text{cm}^2$  at 0.1 in. WC (inch of water column). A total of 36 swatches were taken from each of the six different areas described above (18 each for GB and HD). Also, 12 swatches were cut from the suit pants for a positive control test. Two tests were run for each agent. One test covered four areas of the suit (12 swatches), and the second test covered two areas of the suit (6 swatches). Figure 2 shows the test cell that was used.

For each test, laboratory personnel applied a predetermined liquid agent challenge ( $10\text{g}/\text{m}^2$ ) to the top surface of each swatch. Agent droplets were applied to the surface of the first swatch at time zero. Agent was then applied to the surface of each succeeding swatch at roughly 3-min intervals. The convection tower is connected to the upper chamber of each test cell and a flow of air, from the clean air manifold, sufficient to maintain a differential pressure of 0.1 in. WC, is drawn through the swatch into the lower test cell chamber. The air then passes through the lower test cell chamber outlet and through Teflon tubing to the sampling tee located prior to the linear mass flow controller and vacuum manifold. The test cell was placed into a TOP permeation test apparatus with system control and data acquisition system, fabricated by Battelle Memorial Institute (Columbus, Ohio). Figure 2 shows the permeation apparatus. The test cell inlet was connected to the manifold, which draws conditioned clean air. The test cell outlet was connected to a vacuum source whose flow is maintained by a mass flow controller. A flow of 1.0 L/min was maintained in the lower test cell chamber beneath each swatch.

During the 24-hr test period, gas samples were taken on a sequential basis by a laboratory MINICAMS™ (OI Analytical, CMS Field Products Group, Birmingham, AL) with stream selection system (a miniaturized gas chromatograph (GC) with flame photometric detector and sampling system) from the airstream beneath each swatch, at each sampling tee. See Figure 3. Gas sampling began for the first swatch approximately 3 min following agent application. For HD, subsequent 3-min cycles of the MINICAMS™ were composed of 2.5 min of desorption of collected agent vapor from the pre-concentrator tube (PCT) onto the GC column followed by 0.5 min of gas sampling (collection of agent vapor in the PCT). Sampling is done sequentially through the swatches. The twelve swatches for the first test were sampled

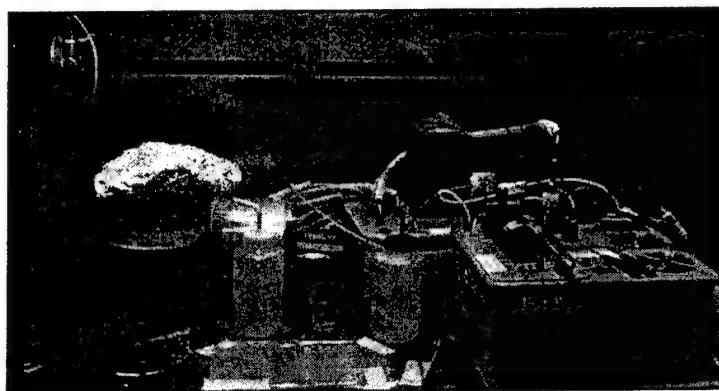
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<sup>4</sup>Test Operations Procedure (TOP) 8-2-501, Permeation and Penetration of Air-Permeable, Semipermeable and Impermeable Materials with Chemical Agents or Simulants (Swatch Testing). U.S. Army Dugway Proving Ground, UT, 3 March 1997, UNCLASSIFIED Report (AD A322329).

approximately every 36 min. The 6 swatches for the second test were sampled approximately every 18 min. For GB, the MINICAMST<sup>TM</sup> cycle was 2.5 min, consisting of 2 min of desorption and 0.5 min of gas sampling. The 12 swatches for the first test were sampled approximately every 30 min. The 6 swatches for the second test were sampled approximately every 15 min.



**Figure 2. Permeation Apparatus and Test Cells**



**Figure 3. MINICAMST<sup>TM</sup> and Stream Selection System (SSS)**

The MINICAMST<sup>TM</sup> first determines the amount of agent vapor in each gas sample. Using this result, the amount (ng) of agent vapor present in the airstream that passes through the swatch over the time from the previous gas sample to the current gas sample is determined by the MINICAMST<sup>TM</sup> permeation software. The calculations assume that the permeation change with time is a straight line over the sampling time interval. The permeation

for each time interval is the average of the permeation rates (flux, ng/cm<sup>2</sup>/min) for the current and previous gas samples multiplied by the sampling time (36 or 18 min). This amount of agent vapor is presumed to be the amount that has permeated the swatch over that time interval. The cumulative mass of agent permeating the swatch per unit area at any elapsed time during the 24-hr test is defined as  $M_f$  (mass/area). It is based on the mass permeated in the time interval over the effective swatch area, which is the opening in the permeation cell (10 cm<sup>2</sup>), and is determined by the MINICAMS™ permeation software. Over the 24-hr test period, a series of  $M_f$  values were calculated for each swatch.

### 3.2.2 Liquid Challenge/Vapor Permeation Testing Analysis.

The tests yielded  $M_f$  data for 18 swatches for each of the two agents over the 24-hr test period. The  $M_f$  data were taken for each of the three swatches from one of the six sampling areas (see Equation 1). The average cumulative permeation ( $M_f$ ) for the three, replicate swatches for each suit area (i.e., chest area) was calculated. This average was then presented, at each of the reported elapsed times, and was assumed to be representative of the suit's permeation resistance at that sampling area. The reported elapsed time for each sampling area was the sum of the elapsed times for the three swatches divided by three.

To estimate the overall suit  $M_f$  at each elapsed time, the simplifying assumption was that exposure is uniform over the entire suit. This permitted the use of the weighting factor scheme developed by Belmonte<sup>5</sup> to determine the weighted average  $M_f$  over the entire suit at each average elapsed time. The average elapsed time was the sum of the reported elapsed times for all the sampling areas divided by the number of sampling areas. The weighting factors were assigned roughly on the basis of surface area, assigning a minimum value of 5%. The weighted average  $M_f$  at any average elapsed time was calculated using the following equation:

$$\begin{aligned} \text{Weighted average } M_f = & 0.4(\text{Chest area } M_f) + 0.35(\text{Thigh area } M_f) + 0.05 \\ & (\text{Upper arm seam } M_f) + 0.05(\text{Lower Leg seam } M_f) + 0.05(\text{Crotch area } M_f) + \\ & 0.05(\text{Hood seam } M_f) \end{aligned} \quad (1)$$

### 3.2.3 Relationship of Liquid Challenge/Vapor Permeation Test Results to Skin Exposure.

The permeation test was designed to distinguish among these material swatches according to their permeation resistance to chemical agents. It was not intended to specifically replicate threat scenarios that may be encountered in actual use or to determine safe wear times. As previously reported by Belmonte,<sup>5</sup> it was instructive to estimate the agent dosage ( $C_{i,skin}$ ) that would result from such a standard agent challenge as a relative indication of possible physiological effects. This was done by converting the weighted average  $M_f$  values to equivalent agent dosages. This relationship was developed by Fedele (written communication, Dr. P. Fedele, Research and Technology Directorate, ERDEC, July 1997) and was reported by Belmonte.<sup>5</sup> For suit materials permeable to airflow, the equation is:

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<sup>5</sup> Belmonte, R.B. *Test Results of Level A Suits to Challenge by Chemical and Biological Warfare Agents and Simulants: Summary Report, ERDEC-TR-513*, U.S. Army Edgewood Research, Development and Engineering Center: Aberdeen Proving Ground, MD, 1998; UNCLASSIFIED Report (AD A353013).

$$C_I T_{\text{skin}} = \{M_f(P_f + q/A)\} / \{(q/A + q^*/A)(P_f + P_s + q/A)\} \quad (2)$$

where

$P_f$  = fabric permeability to agent

$q$  = air flow through the fabric

$q^*$  = air flow added beneath the fabric (for the convective permeation test,  $q^* = 0$ )

$A$  = area of fabric exposed to agent

$P_s$  = skin permeability to agent.

The air flow through the fabric was controlled to maintain a pressure drop of 0.1 in. WC, so  $q/A$  is the fabric air permeability ( $P_a$ ). The equation becomes:

$$C_I T_{\text{skin}} = M_f(P_f + P_a)/P_a(P_f + P_s + P_a) \quad (3)$$

The  $P_a$  must be equal to or greater than 20 cm/min for the convective permeation test to be used. If a fabric provides good protection,  $P_f$  is small. The  $P_s$  is 2.0 cm/min for HD and 0.1 cm/min for GB; small relative to  $P_a$ . The equation becomes:

$$C_I T_{\text{skin}} = M_f/P_a \quad (4)$$

This approach was reviewed by Fedele and found to be a good approximation (written communication, Dr. P. Fedele, Engineering Directorate, ECBC, 29 Mar 00). The agent dosage can then be compared to doses that are known to cause certain levels of toxicity with the assumption that skin permeability is constant for a given agent over all regions of the body.

### 3.2.4 Evaluation Criteria for Liquid Challenge/Vapor Permeation Test Results.

When analyzing the test results, it is useful to determine whether the data indicate that the air-permeable suit provides percutaneous (i.e., skin) protection over some period of time. Mustard vapor can produce erythema<sup>6</sup> (reddening of the skin, certain body regions) at dosages of approximately 100 mg-min/m<sup>3</sup> and can produce vesication (skin burns and blisters, certain body regions) at 200 mg-min/m<sup>3</sup>. Sarin vapor can produce incapacitation<sup>6</sup> (twitching, convulsions, or loss of consciousness) at unprotected, percutaneous dosages of approximately 8000 mg-min/m<sup>3</sup> and can be lethal at unprotected, percutaneous dosages of 15000 mg-min/m<sup>3</sup> where exposed persons are healthy, young, fit, and well-nourished males of approximately 70-kg mass. People, who are smaller, less fit, etc., may exhibit adverse effects at lower doses ( $C_I t_{\text{skin}}$ ).

The simplifying assumption was that the suit was exposed to a uniform liquid GB challenge over its entire surface, resulting in a uniform exposure of all body regions to GB vapor. This is conservative because the areas likely to receive more exposure (hands, arms, chest, and back) would also be those less sensitive. Therefore, the amount of agent per unit area (weighted average  $M_f$ ) necessary to permeate the suit to produce a predetermined physiological effect was estimated by using each of the above dosages and that suit's fabric air permeability ( $P_a$ ). These values were used to determine the physiologically derived breakthrough times in the graphs of

<sup>6</sup>Belmonte, R.B. *Test Results of Level A Suits to Challenge by Chemical and Biological Warfare Agents and Simulants: Summary Report, ERDEC-TR-513*, U.S. Army Edgewood Research, Development and Engineering Center: Aberdeen Proving Ground, MD, 1998; UNCLASSIFIED Report (AD A353013).



weighted average  $M_f$  versus time given in Appendix B and summarized in Table 1. The critical breakthrough dosages, used to calculate threshold  $M_f$  values, are considered to be 100 mg-min/m<sup>3</sup> for HD (reddening of skin) and 8000 mg-min/m<sup>3</sup> for GB (incapacitation – twitching, convulsions, or loss of consciousness). A physiologically derived breakthrough time is the time when the weighted average  $M_f$  equals the threshold  $M_f$  calculated from Equation 4.

Table 1. Agent Breakthrough Criteria

Suit	Agent	Breakthrough Dosage (mg-min/m <sup>3</sup> )	Physiological Effect	Fabric Air Permeability ( $P_a$ ) at 0.1 in. WC (cm/min)	Threshold $M_f$ (ng/cm <sup>2</sup> )
SARATOGA™ Hammer Suit	HD	100	Erythema	56	5,600
	HD	200	Vesication	56	11,200
	GB	8,000	Incapacitation	56	448,000
	GB	15,000	Lethality	56	840,000

Breakthrough time should not be interpreted as the time that a suit can be safely worn, either for HD or GB. Breakthrough times should only be used to compare suit materials.

### 3.3 Protection Factor (Aerosol) Testing.

A second test was performed to determine the suit's ability to protect the wearer from an aerosol threat. This test involved human test subjects donning the suit and entering a chamber filled with a challenge concentration of corn oil aerosol. This aerosol is kept between 20 and 40 mg/m<sup>3</sup>, and the particle size is between 0.4 and 0.6  $\mu$  Mass Median Aerodynamic Diameter (MMAD). That concentration and size ranges are what best simulate chemical and biological agent aerosols. While in the chamber, the subjects perform exercises designed to stress the seals of the equipment. If the suit were to leak, the corn oil aerosol would enter the suit and be sampled by the laser photometers. The measure of the suit's performance for this test is the protection factor (PF).

#### 3.3.1 Protection Factor Testing Procedures.

Prior to test day, the PF Test Facility received eight complete suit ensembles (jackets and trousers), all of which were of the large/regular size. Two sampling probes were installed into each jacket. One was located in the upper arm region, and the second was placed in the neck region. These areas were selected as the most likely place for aerosol leakage to occur during a worst-case scenario. These two probes were then connected to a single sampling tube using a 'Y' connector. Each jacket and trouser were paired and individually numbered for uniqueness throughout testing.

On test day, 30 military volunteers arrived at the PF Test Facility to participate in the test. Anthropometric measurements were taken from the volunteers including chest, waist, and height. From these measurements, 16 subjects were chosen to best fit the suits that were provided to the facility. The subjects then completed volunteer agreements, while the PF Test Facility personnel explained the test procedure. The first eight subjects then readied themselves to begin the test. They donned the suit with the help of the PF Test Facility personnel.

A correctly sized M40 mask was also expertly donned by the facility personnel onto the subjects. The subjects also wore inner cloth gloves and butyl rubber outer gloves. Sampling lines were then attached to the probes in the suits. Once ready, the subjects were led into the chamber where they were attached to sampling tubes connected to laser photometers located outside of the chamber. The test was then started. The subjects performed the following eight 1-min exercises:

1. Normal breathing
2. Bend forward, touch toes
3. Jog in place
4. Raise arms above head and look up
5. Bend knees and squat
6. Crawl on hands and knees
7. Twist torso with hands folded in front of chest
8. Normal breathing

The test facility personnel communicated each exercise to the subjects from outside the chamber. When the test was complete, the subjects disconnected their sampling tubes and exited the chamber. All 16 subjects performed a trial twice for a total of 32 data points.

### 3.3.2 Protection Factor Data Analysis Method.

Suit performance was quantified in terms of a PF. Just before the test was started, the photometer takes a challenge aerosol concentration reading. Throughout the test, a sample was pulled continuously from within the suit. The PF was calculated by determining the ratio of the challenge aerosol concentration to the in-suit aerosol concentration as quantified by integrating the curve of the voltage output from the photometer over a time interval (1 min per exercise). A PF was calculated for each individual exercise ( $PF_i$ ):

$$PF_i = \frac{\text{Challenge Concentration}}{\text{In-suit Concentration}} \quad (5)$$

Each  $PF_i$  for that trial was then used to calculate an overall PF for a subject ( $PF_o$ ) using the harmonic average as follows:

$$PF_o = n \left( \sum_{i=1}^n \frac{1}{PF_i} \right)^{-1} \quad (6)$$

where  $n$  is the number of exercises. The  $PF_o$  is affected most by the smallest  $PF_i$ . Under the conditions of this test and the sensitivity of the photometer, the maximum PF that can be reported is 100,000. The data acquisition computer performed all calculations at the time of the test. Appendix E shows the  $PF_i$  and  $PF_o$  for each subject on each trial.



#### 4. RESULTS AND DISCUSSION

##### 4.1 Swatch Test Results.

Five thickness measurements for each swatch were taken prior to testing using an Ames dial comparator (B. C. Ames Company, Waltham, MA). The average thicknesses are given in Appendixes D and E. The MINICAMS™ minimum detection limit for HD and GB was set at 0.57 ng for all tests. No visible damage was observed on any of the swatches from either HD or GB exposure. The HD weighted average  $M_f$  data are presented in Table B-1 and the GB weighted average  $M_f$  data are presented in Table B-2. The HD and GB individual swatch data are given in Appendix D. The plot of the weighted average HD permeation is shown in Figure B-1, and the plot of weighted average GB permeation is shown in Figure B-2. The plot of HD permeation by sampling area is shown in Figure B-3, and the plot of GB permeation by sampling area is shown in Figure B-4. The results are summarized in Table 2.

Table 2. Overall Test Results

Breakthrough Time (minutes)	
Incapacitation	Erythema
GB	HD
>396	253

These breakthrough criteria are not to be construed as safe threshold values; they are being used only to rank suits.

##### 4.2 Aerosol Test Results.

The overall PF values for all of the trials were between 1.9 and 3.4. Due to the low values in PF, the operational exercises were not tested with this suit. The subjects only performed the eight exercises listed in Section 3.3.1. Table 3 lists the passing percentage for this suit at point estimates derived from Army requirements. The passing percentage represents the percentage of trials that achieved an overall PF greater than the PF listed in the left column.

Table 3. PF Test Results

PF	PASS %
0	100.00
2	93.75
5	0.00

##### 4.3 Discussion of Results.

The test data reveals that the SARATOGA™ Hammer Suit tested can protect the wearers from liquid CW agents but that the suit provides minimal protection from a vapor threat. Breakthrough times should not be interpreted as the time that a suit can be safely worn, either for HD or GB. Breakthrough times should only be used to compare suit materials. In other words, the suit material does provide limited skin protection, but the suit itself provides little or no skin protection.

**Blank**

## ACRONYMS AND ABBREVIATIONS

A	Surface area of fabric exposed to agent
ccm	Cubic centimeters per minute
CFR	Code of Federal Regulations
Ct	Cumulative vapor exposure, product of vapor concentration (mg/m <sup>3</sup> ) and time (minutes)
C <sub>It<sub>skin</sub></sub>	Cumulative vapor exposure to skin
cm <sup>2</sup>	Square centimeters
CW	Chemical Warfare
°F	Temperature in degrees Fahrenheit
delta p	Differential pressure
DoD	Department of Defense
ECBC	U.S. Army Edgewood Chemical Biological Center
ERDEC	U.S. Army Edgewood Research, Development and Engineering Center
g	Gram
GB	Sarin, Isopropylmethylphosphonofluoridate
GC	Gas chromatograph
HD	Sulfur Mustard; 2,2'-Dichlorodiethylsulfide
inch WC	Inch of water column (equals 249.0889 pascals (Pa))
kPa	Kilopascals (one kilopascal equals 1000 pascals (Pa))
L	Liter
M <sub>f</sub>	Cumulative mass permeation through the fabric
MMAD	Mass Median Aerodynamic Diameter
m <sup>2</sup>	Square meters
m <sup>3</sup>	Cubic meters
mg	Milligram
μL	Microliter
ng	Nanogram
NBC	Nuclear, Biological and Chemical
OSHA	Occupational Safety and Health Administration
PCT	Pre-concentrator tube
PF	Protection Factor
PPE	Personal Protective Equipment
P <sub>a</sub>	Fabric air permeability
P <sub>f</sub>	Fabric agent permeability
P <sub>s</sub>	Skin permeability
PF	Protection Factor
q	Airflow through fabric, cubic centimeters/min
q*	Air flow added beneath fabric, cubic centimeters/min
RH	Relative Humidity
SCBA	Self-Contained Breathing Apparatus
TOP	Test Operations Procedure

**Blank**

## **APPENDIX A**

### **MODIFIED CONVECTIVE PERMEATION TEST PROCEDURE**

This test procedure was adapted from Test Operations Procedure (TOP) 8-2-501, Permeation and Penetration of Air-Permeable, Semipermeable and Impermeable Materials with Chemical Agents or Simulants (Swatch Testing). U.S. Army Dugway Proving Ground, UT. 3 March 1997, UNCLASSIFIED Report (AD A322329).

1. Upon receipt of an item, all available information will be recorded; date of manufacture, lot number, serial number, materials of construction, etc. Digital pictures will be taken of the label(s) and packaging (if any).

2. From each overgarment, two 6-in. diameter material swatches shall be cut; one from the front chest/abdominal area and one from the front thigh area. These swatches will be tested for air permeability IAW paragraph 3.2 of TOP 8-2-501 and the results averaged. For undergarments, an equal number of like-sized swatches will be cut from the undergarment (same locations as above) and from the clothing (e.g. police uniform, firefighter's bunker gear) worn over the undergarment. Air permeability will then be determined on the outer clothing/undergarment swatch ensemble, layered as worn. The average air permeability must be greater than  $20 \text{ cm}^3/\text{min}/\text{cm}^2$  at 0.1 in. of water (inch WC) for the convective permeation procedure to be used.

3. From each overgarment, three  $1\text{-}\frac{15}{16}$ -in. diameter material swatches will be taken from the chest area and 3 like diameter material swatches will be taken from the thigh area, adjacent to the air permeability swatch locations, for HD. The same number of material swatches from the same locations will be taken for GB. Depending upon the overgarment configuration, three seam swatches (same diameter) will be taken from the upper arm, three seam swatches will be taken from the lower leg, and three swatches, including at least one seam, will be taken from the crotch area for HD and an equal number for GB. If a hood, socks, or gloves are present; three seam swatches will be taken from each item for HD and three for GB. Each swatch will be placed in an airtight bag and given a unique serial number, which will be placed on the bag. A list of serial numbers will be kept with the swatches. For undergarments, an equal number of like-sized swatches will be cut from the undergarment (same locations as above) and from the clothing worn over the undergarment. The outer clothing/undergarment swatch ensemble will be layered as worn and stored as above.

4. The environmental chamber will be controlled at a temperature of  $90^\circ\text{F} \pm 2^\circ$ . The temperature will be checked weekly with a calibrated meter. The test cell air will be drawn from a manifold supplied with clean air (flow set at 20-30 L/min, excess vented into the test cabinet) from the Miller-Nelson unit set at  $90^\circ\text{F}$  and 80 % RH. There will be no system control and data acquisition system due to budget constraints. The cabinet temperature will be recorded in a computer file. The temperature and RH of the test cell air will be manually recorded.

5. The TOP test cell with convective permeation tower will be used. When assembling, the cell lugs will be tightened by hand to finger tight. The conditioned air will flow

from the manifold into the top of the tower, through each swatch and will exit the bottom of the cell. For each cell, the port on the side of the tower and the tee at the cell exit will be connected to a differential pressure gage. The flow rate from each cell will be controlled with a linear mass flow controller connected to the vacuum manifold. Each flow rate will be set to a value that yields a reading of 0.1 in. of water on the differential pressure gage. The gage readings will be checked with a calibrated differential pressure meter weekly. Flow rates will be manually recorded.

6. Each test cell will be checked for leaks after assembly by connecting it to the vacuum source and checking that the inlet flow is the same as the outlet flow on the mass flow controller (cell lugs will be retightened if flows don't match).

7. The sample swatches will serve as their own negative controls while being preconditioned for 2 hr prior to agent contamination by being MINICAMST<sup>TM</sup> monitored. A SARATOGA<sup>TM</sup> material swatch will be used as a positive control for each test (six test swatches and one SARATOGA<sup>TM</sup> swatch). To establish a baseline, at least two tests using SARATOGA<sup>TM</sup> control material only (14 swatches) will be conducted with HD and two tests will be conducted with GB prior to commencement of testing.

8. Agents GB and HD will be used. The contamination density will be 10 g/m<sup>2</sup> (eight 1  $\mu$ L HD droplets or ten 1  $\mu$ L GB droplets). A robotic agent application system is not available due to budget constraints. The agent will be applied using the click/touch method with a Hamilton repeating dispenser. The contamination density will be checked each test day by placing 10 droplets into a pre-weighed flask or vial containing appropriate solvent, weighing the vial or flask on a calibrated balance and calculating the average droplet weight. Alternatively, one droplet may be placed into a vial containing appropriate solvent and the amount of agent in the droplet determined by an appropriate analytical procedure such as gas chromatography.

9. Seven swatches will be tested at once. MINICAMST<sup>TM</sup> with stream selection system will monitor vapor permeation with a 3-min cycle. There will be three blank sampling intervals following the positive control swatch. Each swatch will be sampled once every 30 min. The MINICAMST<sup>TM</sup> will be standardized weekly.

10. The test length will be 10 hr; 2 hr for conditioning and 8 hr after agent contamination. Each swatch shall complete four MINICAMST<sup>TM</sup> sampling cycles prior to contamination.

11. The test cells and o-rings will be aerated for at least 24 hr between uses. No other cleaning method will be used. O-rings will be completely replaced on a weekly basis.

12. The data to be reported are cumulative permeation (ng/cm<sup>2</sup>) versus elapsed time (minutes) and Ct (cumulative mass/flow rate, ng-min/cm<sup>3</sup>) versus elapsed time for each swatch. All recorded data will be placed in laboratory notebooks and a technical report will be drafted at the conclusion of this effort.

## APPENDIX B TEST RESULTS

**Table B-1. SARATOGA™ Hammer Suit Average Cumulative HD Permeation**

Time (min)	Thigh Material (ng/cm <sup>2</sup> )	Time (min)	Chest Material (ng/cm <sup>2</sup> )	Time (min)	Crotch Seam and No Seam (ng/cm <sup>2</sup> )	Time (min)	Hood Seam (ng/cm <sup>2</sup> )	Time (min)	Upper Arm Seam (ng/cm <sup>2</sup> )	Time (min)	Lower Leg Seam (ng/cm <sup>2</sup> )	Average Time (min)	Weighted Average M <sub>i</sub> (ng/cm <sup>2</sup> )
4	12	13	18	22	255	31	547	6	6	15	174	15	60
40	857	49	324	58	1382	68	1878	24	147	33	753	46	638
77	2442	86	893	95	2746	104	3039	42	461	51	1585	76	1603
113	3956	122	1482	131	3875	140	3797	60	856	69	2412	106	2525
149	5263	158	2014	167	4812	176	4364	78	1254	87	3119	136	3325
185	6517	194	2509	203	5649	212	4875	97	1615	106	3716	166	4077
221	7658	230	2976	239	6304	249	5320	115	1931	124	4237	196	4760
258	8476	267	3375	276	6740	285	5632	133	2203	142	4702	227	5281
294	9015	303	3685	312	7048	321	5831	151	2433	160	5112	257	5650
330	9395	339	3933	348	7282	357	5994	169	2628	178	5472	287	5930
366	9657	375	4163	384	7452	393	6149	187	2800	196	5797	317	6155
402	9863	411	4343	420	7571	430	6295	205	2955	214	6098	347	6335
439	10038	448	4458	457	7661	466	6403	223	3099	232	6381	377	6473
475	10183							241	3235	250	6649		
								259	3365	268	6906		
								278	3489	287	7154		
								296	3607	305	7389		
								314	3720	323	7599		
								332	3825	341	7782		
								350	3922	359	7942		
								368	4008	377	8081		
								386	4085	395	8200		
								404	4152	413	8296		
								422	4207	431	8371		
								440	4254	449	8431		
								459	4292	468	8480		
								477	4323				

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The average time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average  $M_i = 0.4(\text{chest area } M_i) + 0.35(\text{thigh area } M_i) + 0.05(\text{upper arm seam } M_i) + 0.05(\text{lower leg seam } M_i) + 0.05(\text{crotch area } M_i) + 0.05(\text{hood seam } M_i)$ .

**Table B-2. SARATOGA™ Hammer Suit Average Cumulative GB Permeation**

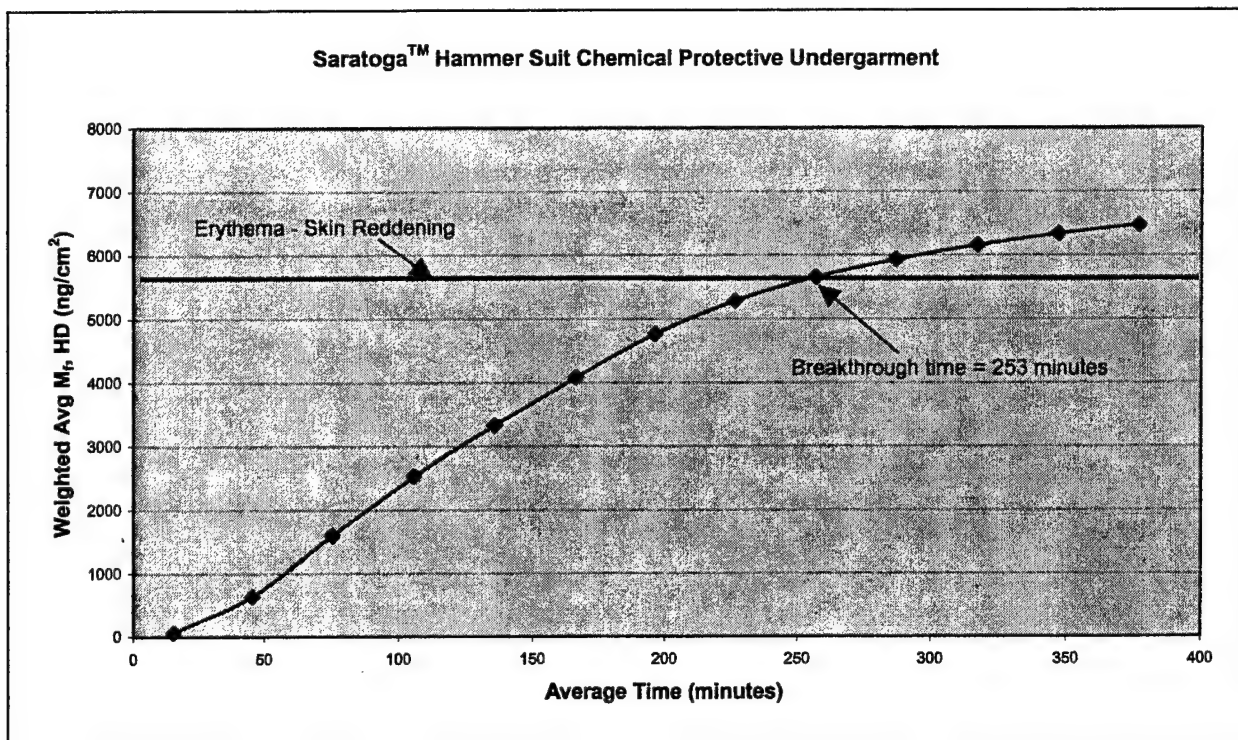
Time (min)	Thigh Material (ng/cm <sup>2</sup> )	Time (min)	Chest Material (ng/cm <sup>2</sup> )	Time (min)	Crotch Seam and No Seam (ng/cm <sup>2</sup> )	Time (min)	Hood Seam (ng/cm <sup>2</sup> )	Time (min)	Upper Arm Seam (ng/cm <sup>2</sup> )	Time (min)	Lower Leg Seam (ng/cm <sup>2</sup> )	Average Time (min)	Weighted Average M <sub>i</sub> (ng/cm <sup>2</sup> )
3	1020	11	713	24	4794	19	5475	5	806	12	2554	12	1324
33	12308	41	4209	51	12114	46	17059	25	7215	33	8838	38	8253
63	18208	71	6381	77	14578	72	22421	45	12128	53	12210	64	11992
93	20830	101	7623	104	15815	99	25065	65	15212	73	13776	89	13833
123	22833	131	8583	131	16719	126	26732	85	17201	93	14722	115	15194
154	24548	161	9405	157	17450	152	27934	105	18511	113	15392	140	16318
184	26084	191	10154	184	18072	179	28917	125	19523	133	15923	166	17313
214	27478	221	10828	211	18627	206	29753	145	20314	153	16370	191	18202
244	28733	251	11447	237	19145	232	30492	165	20964	173	16760	217	19004
274	29909	281	12037	264	19629	259	31163	185	21541	193	17116	243	19755
304	31045	311	12596	291	20080	286	31771	205	22055	213	17439	268	20471
334	32119	341	13127	317	20504	312	32330	225	22515	233	17732	294	21146
364	33156	371	13635	344	20918	339	32855	245	22924	253	18006	319	21794
394	34163	401	14120	371	21320	366	33352	265	23299	273	18266	345	22417
424	35129	431	14589	398	21695	393	33826	285	23648	293	18508	370	23015
454	36053	461	15041	424	22053	419	34275	305	23974	313	18734	396	23587
								325	24276	333	18954		
								345	24559	353	19167		
								365	24835	373	19368		
								385	25099	393	19560		
								405	25347	413	19748		
								425	25589	433	19931		
								445	25829	453	20109		
								465	26056	473	20284		

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

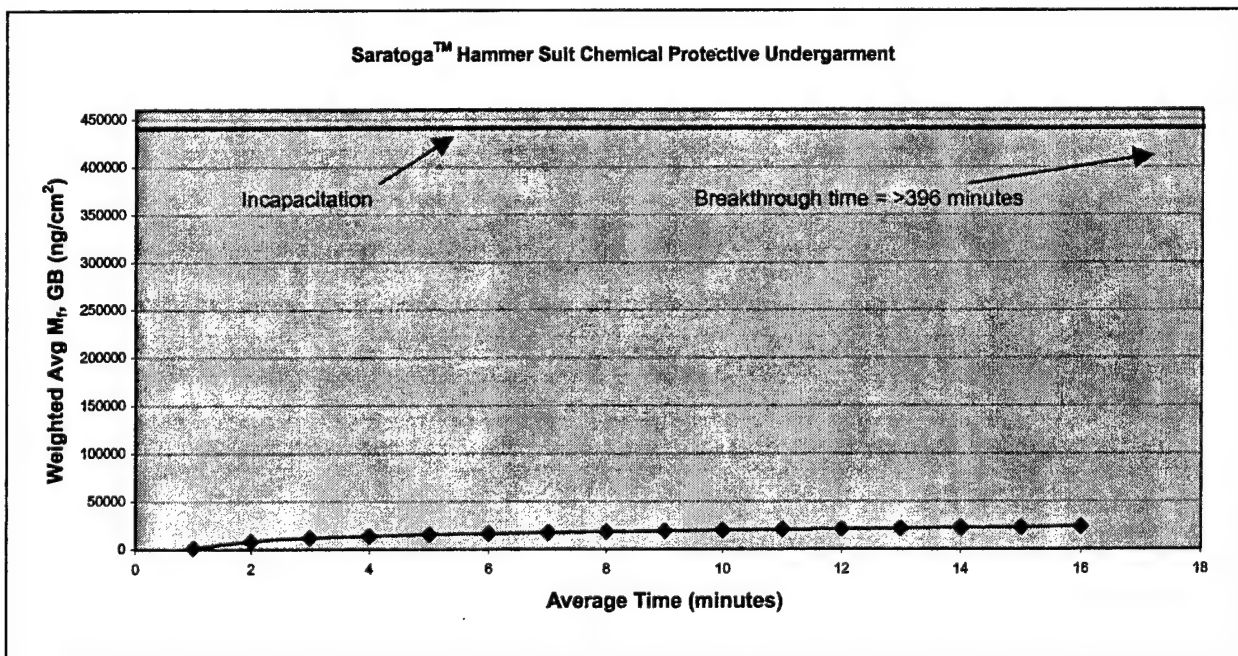
Note 2: The average time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average  $M_i = 0.4(\text{chest area } M_i) + 0.35(\text{thigh area } M_i) + 0.05(\text{upper arm seam } M_i) + 0.05(\text{lower leg seam } M_i) + 0.05(\text{crotch area } M_i) + 0.05(\text{hood seam } M_i)$ .





**Figure B-1. SARATOGA™ Hammer Suit – Weighted Average HD Permeation**



**Figure B-2. SARATOGA™ Hammer Suit – Weighted Average GB Permeation**

# Saratoga™ Hammer Suit

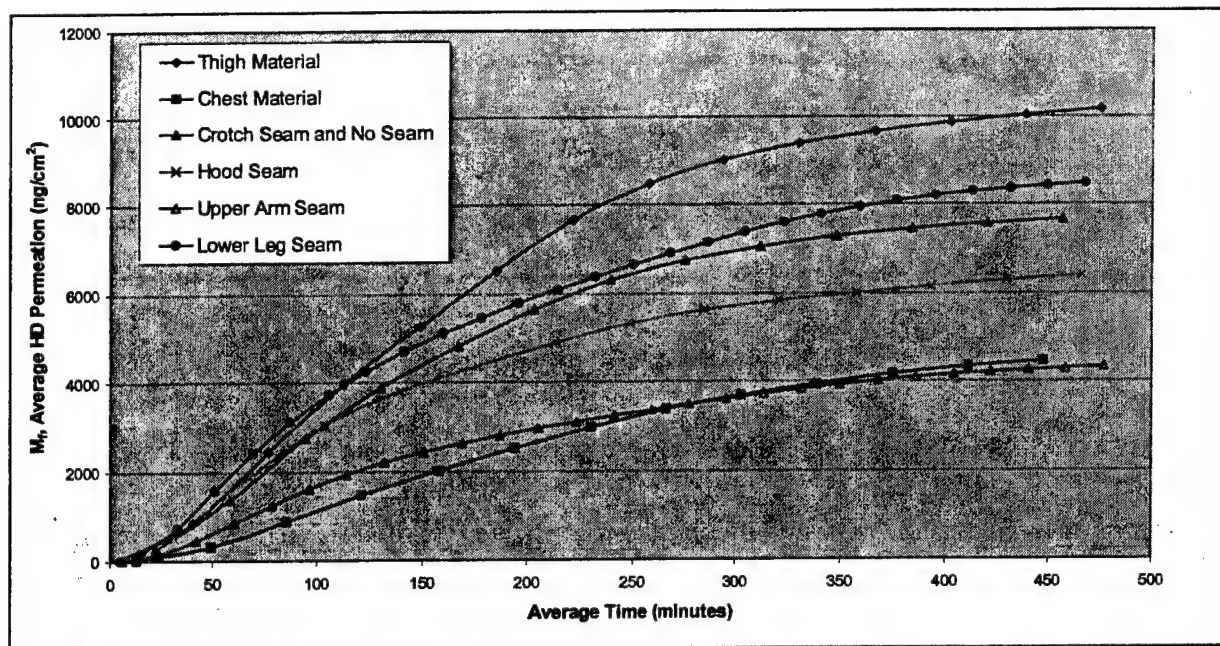


Figure B-3. SARATOGA™ Hammer Suit – HD Permeation by Sampling Area

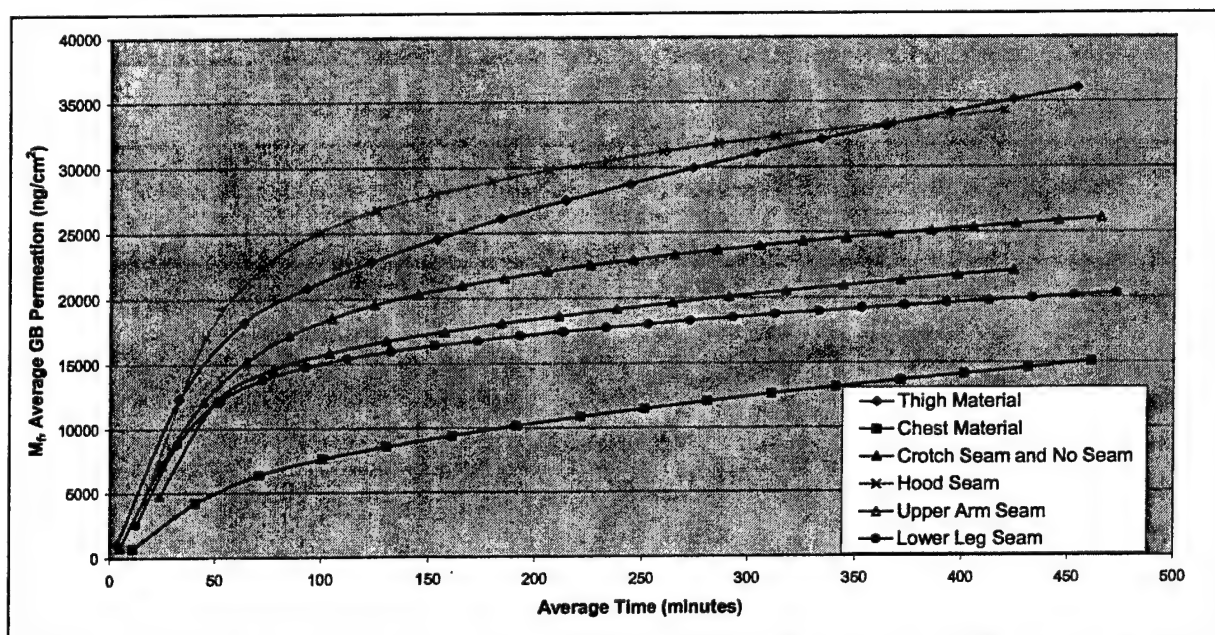
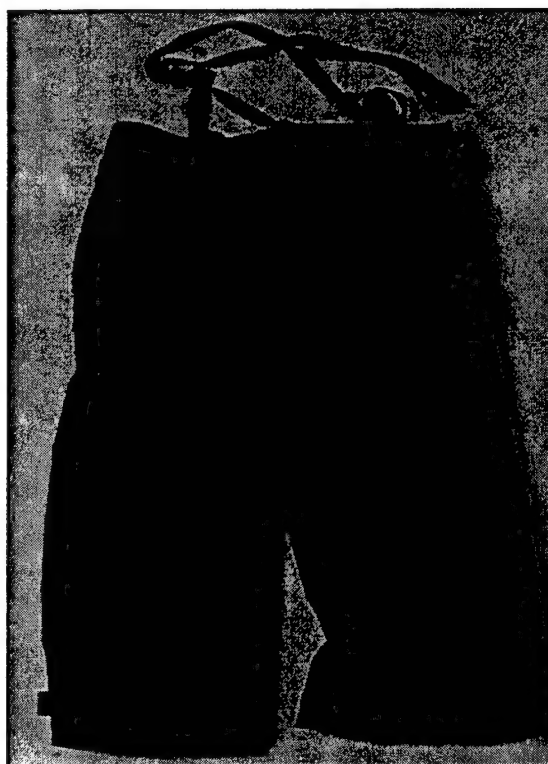


Figure B-4. SARATOGA™ Hammer Suit – GB Permeation by Sampling Area

**APPENDIX C**  
**SARATOGA™ HAMMER SUIT PHOTOS**



**Figure C. SARATOGA™ Hammer Suit Coat and Trousers**

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**APPENDIX D**  
**NEGATIVE/POSITIVE CONTROL AND INDIVIDUAL TEST DATA**

Air-Permeable SARATOGA™ Hammer Suit vs. HD Liquid (10g/m<sup>2</sup>)  
Negative Control Test  
Modified Convective Permeation Test at 90 °F and 35% RH, 07/11/03

**Table D-1. Individual Negative Control Measurements for HD**

Swatch #	Average Thickness (inches)	Permeation Cell#	Computer Average Flow (ccm)	Pressure Difference, (inch WC)
1	0.045	6	402	0.103
2	0.045	1	430	0.100
3	0.045	3	419	0.103
4	0.045	4	394	0.109
5	0.045	10	431	0.097
6	0.045	12	403	0.098
7	0.045	11	410	0.098
8	0.045	9	489	0.103
9	0.045	7	339	0.103
10	0.045	2	430	0.099
11	0.044	5	421	0.098
12	0.045	8	411	0.100

**Notes:**

- Chemical Protective Overgarment for Domestic Preparedness, SARATOGA™ Hammer Suit
- Made by: Tex-Shield, Inc. 2300 M Street N.W. Suite 800 Washington, DC 20037
- Suit inspected 1 April 03 and found okay. Size LR, lot# BL100401891
- Swatches were taken from the front of the left pant leg; they consisted of a single layer of fabric and a layer of carbon material.

1-<sup>15</sup>/<sub>16</sub>-in. swatch

Used MINICAMS™ GC/FPD

Min. Detection Limit = 0.57 ng

Total Test Time = 33:15

Average Chamber Temperature = 32.2°C (90.0 °F)

Average Manifold Temperature = 32.1°C (89.8 °F)

Average Relative Humidity = 36.7 %

Average Computer Flow Rate = 415 ccm

Average Pressure Difference = 0.101 in. WC

**Table D-2. Individual M<sub>f</sub> Negative Control Values at Sampling Times for HD**

Time (min)	S #1	Time (min)	S #2	Time (min)	S #3	Time (min)	S #4	Time (min)	S #5	Time (min)	S #6	Time (min)	S #7	Time (min)	S #8	Time (min)	S #9	Time (min)	S #10	Time (min)	S #11	Time (min)	S #12
0	0	3	0	6	0	9	0	12	0	15	0	18	0	21	0	24	0	27	0	30	0	33	0

**Note:**

- In all M<sub>f</sub> tables, zero (0) is equivalent to non-detectable (ND).

Air-Permeable SARATOGA™ Hammer Suit vs. GB Liquid (10g/m<sup>2</sup>)  
 Negative Control Test  
 Modified Convective Permeation Test at 90 °F and 35% RH, 07/22/03

**Table D-3. Individual Negative Control Measurements for GB**

Swatch #	Average Thickness (inches)	Permeation Cell#	Computer Average Flow (ccm)	Pressure Difference, (inch WC)
1	0.045	5	371	0.100
2	0.045	3	465	0.099
3	0.045	12	409	0.100
4	0.045	4	364	0.100
5	0.045	8	355	0.100
6	0.045	2	388	0.100
7	0.045	9	370	0.100
8	0.045	7	330	0.100
9	0.045	6	439	0.099
10	0.045	10	365	0.098
11	0.045	1	351	0.099
12	0.045	11	412	0.100

**Notes:**

-Swatches were taken from the back of the lower left pant leg; they consisted of a single layer of fabric and a layer of carbon material.

1-<sup>15</sup>/<sub>16</sub>-in. swatch

Used MINICAMS™ GC/FPD

Min. Detection Limit = 0.57 ng

Total Test Time = 58:19

Average Chamber Temperature = 32.2 °C (90.0 °F)

Average Manifold Temperature = 32.1 °C (89.8 °F)

Average Relative Humidity = 35.4%

Average Computer Flow Rate = 385 ccm

Average Pressure Difference = 0.100 in. WC

**Table D-4. Individual M<sub>f</sub> Negative Control Values at Sampling Times for GB**

Time (min)	S #1	Time (min)	S #2	Time (min)	S #3	Time (min)	S #4	Time (min)	S #5	Time (min)	S #6	Time (min)	S #7	Time (min)	S #8	Time (min)	S #9	Time (min)	S #10	Time (min)	S #11	Time (min)	S #12
1	0	3	0	6	0	8	0	11	0	13	0	16	0	18	0	21	0	23	0	26	0	28	0
31	0	33	0	36	0	38	0	41	0	43	0	46	0	48	0	51	0	53	0	56	0	58	0

**Notes:**

-In all M<sub>f</sub> tables, zero (0) is equivalent to non-detectable (ND).



Air-Permeable SARATOGA™ Hammer Suit vs. HD Liquid (10g/m<sup>2</sup>)  
Positive Control Test  
Modified Convective Permeation Test at 90 °F and 35% RH, 07/14/03

**Table D-5. Individual Positive Control Measurements for HD**

Swatch #	Average Thickness (Inches)	Permeation Cell#	Computer Average Flow (ccm)	Pressure Difference (in WC)
1	0.045	6	412	0.104
2	0.045	1	440	0.102
3	0.045	3	429	0.107
4	0.045	4	383	0.107
5	0.045	10	451	0.104
6	0.045	12	433	0.105
7	0.045	11	430	0.107
8	0.045	9	499	0.122
9	0.045	7	329	0.101
10	0.045	2	439	0.120
11	0.044	5	431	0.127
12	0.045	8	422	0.101

1-<sup>15</sup>/<sub>16</sub>-in. swatch

Used MINICAMS™ GC/FPD

Min. Detection Limit = 0.57 ng

Total Test Time = 7:59:09

Average Chamber Temperature = 32.2 °C (90.0 °F)

Average Manifold Temperature = 32.0 °C (89.6 °F)

Average Relative Humidity = 35.2%

Average Computer Flow Rate = 425 ccm

Average Pressure Difference = 0.109 in. WC

Air-Permeable SARATOGA™ Hammer Suit vs. HD Liquid (10g/m<sup>2</sup>),  
Positive Control Test  
Modified Convective Permeation Test at 90 °F and 35% RH, 07/14/03

**Table D-6. Individual M<sub>f</sub> Positive Control Values at Sampling Times for HD**

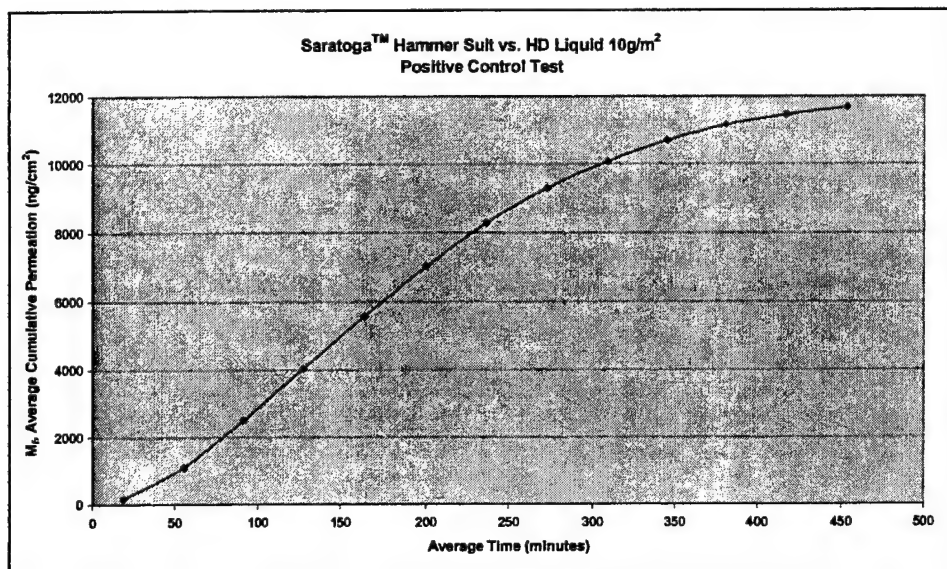
Time (min)	S #1	Time (min)	S #2	Time (min)	S #3	Time (min)	S #4	Time (min)	S #5	Time (min)	S #6	Time (min)	S #7	Time (min)	S #8	Time (min)	S #9	Time (min)	S #10	Time (min)	S #11	Time (min)	S #12
3	5	6	18	9	37	12	65	15	132	18	69	21	118	24	265	27	223	30	351	33	378	36	436
39	510	42	589	45	714	48	843	51	1219	54	1096	57	999	60	1530	63	1158	66	1571	69	1485	72	1572
75	1529	78	1624	81	1860	84	2095	87	2833	90	2953	93	2421	96	3320	99	2492	102	3223	105	2908	108	2994
111	2729	114	2800	117	3126	120	3457	123	4560	126	4893	129	3930	132	5184	135	3920	138	4960	141	4423	144	4502
147	3957	150	4020	153	4421	156	4806	159	6319	162	6828	165	5450	168	7010	171	5350	174	6636	177	5947	181	6069
184	5192	187	5286	190	5762	193	6146	196	8068	199	8607	202	6954	205	8769	208	6739	211	8060	214	7166	217	7428
220	6396	223	6580	226	7173	229	7491	232	9603	235	10063	238	8343	241	10258	244	8036	247	9140	250	7952	253	8331
256	7541	259	7863	262	8618	265	8671	268	10711	271	11077	274	9409	277	11243	280	9070	283	9903	286	8478	289	8884
292	8638	295	9197	298	9955	301	9552	304	11463	307	11722	310	10145	313	11873	316	9761	319	10433	322	8864	325	9278
328	9752	331	10413	334	11050	337	10207	340	12032	343	12212	346	10678	349	12327	352	10205	355	10809	358	9153	362	9577
365	10626	368	11199	371	11848	374	10683	377	12446	380	12569	383	11052	386	12655	389	10512	392	11074	395	9367	398	9807
401	11117	404	11655	407	12353	410	10992	413	12728	416	12814	419	11320	422	12903	425	10743	428	11276	431	9537	434	9990
437	11450	440	11979	443	12680	446	11206	449	12943	452	13005	455	11530	458	13101	461	10931	464	11442	467	9677	470	10145
473	11706	476	12234	479	12933																		

**Notes:**

-In all M<sub>f</sub> tables, zero (0) is equivalent to non-detectable (ND).



Air-Permeable SARATOGA™ Hammer Suit vs. GB Liquid (10g/m<sup>2</sup>)  
Positive Control Test  
Modified Convective Permeation Test at 90 °F and 35% RH, 07/22/03



**Table D-7. Individual Positive Control Measurements for GB**

Swatch #	Average Thickness (inches)	Permeation Cell#	Computer Average Flow (ccm)	Pressure Difference (in WC)
1	0.045	5	372	0.100
2	0.045	3	465	0.102
3	0.045	12	409	0.100
4	0.045	4	364	0.104
5	0.045	8	356	0.099
6	0.045	2	388	0.098
7	0.045	9	370	0.100
8	0.045	7	329	0.103
9	0.045	6	439	0.095
10	0.045	10	365	0.102
11	0.045	1	351	0.099
12	0.045	11	412	0.105

**Notes:**

- Swatches were taken from the back of the lower left pant leg; they consisted of a single layer of fabric and a layer of carbon material.
- Agent beaded up on the surface of the swatch.

1-<sup>15</sup>/<sub>16</sub>-in. swatch

Used MINICAMS™ GC/FPD

Min. Detection Limit = 0.57 ng

Total Test Time = 7:59:24

Average Chamber Temperature = 32.2 °C (90.0 °F)

Average Manifold Temperature = 32.1 °C (89.8 °F)

Average Relative Humidity = 35.9%

Average Computer Flow Rate = 385 ccm

Average Pressure Difference = 0.101 in. WC

Air-Permeable SARATOGA™ Hammer Suit vs. GB Liquid (10g/m<sup>2</sup>)  
Positive Control Test  
Modified Convective Permeation Test at 90 °F and 35% RH, 07/22/03

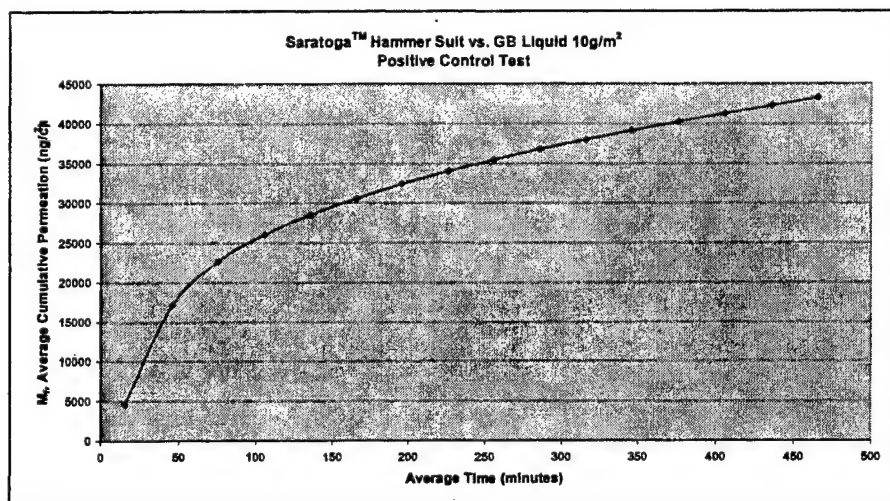
**Table D-8. Individual M<sub>f</sub> Positive Control Values at Sampling Times for GB**

Time (min)	S #1	Time (min)	S #2	Time (min)	S #3	Time (min)	S #4	Time (min)	S #5	Time (min)	S #6	Time (min)	S #7	Time (min)	S #8	Time (min)	S #9	Time (min)	S #10	Time (min)	S #11	Time (min)	S #12
2	493	4	1544	7	2182	9	2874	12	2935	14	4987	17	4594	19	5230	22	8035	24	7771	27	5034	29	9989
32	15705	34	17585	37	16169	39	14942	42	13135	44	18583	47	15732	49	16140	52	22191	54	19522	57	12540	59	23828
62	25847	64	25566	67	22892	69	19499	72	17606	74	23836	77	20561	79	20839	82	27317	84	23166	87	15542	89	29617
92	30375	94	29805	97	26771	99	22192	102	20517	104	27323	107	23798	109	24104	112	30815	114	25652	117	17497	119	33255
122	33653	124	32959	127	29644	129	24121	132	22776	134	29928	137	26329	139	26566	142	33553	144	27555	147	19046	149	35980
152	36173	154	35487	157	31954	159	25785	162	24639	164	32101	167	28394	169	28623	172	35879	174	29200	177	20383	179	38319
182	38344	184	37757	187	33975	189	27243	192	26298	194	34045	197	30190	199	30493	202	37924	204	30683	207	21577	209	40330
212	40315	214	39781	217	35682	219	28523	222	27752	224	35771	227	31791	229	32137	232	39704	234	32041	237	22668	239	42040
242	42122	244	41566	247	37218	249	29888	252	29042	254	37305	257	33257	259	33599	262	41316	264	33280	267	23624	269	43590
272	43776	274	43207	277	38613	279	30777	282	30248	284	38735	287	34575	289	34966	292	42773	294	34381	297	24475	299	44978
302	45282	304	44712	307	39918	309	31772	312	31357	314	40058	317	35754	319	36205	322	44122	324	35411	327	25294	329	46257
332	46687	334	46078	337	41150	339	32718	342	32397	344	41270	347	36866	349	37323	352	45401	354	36399	357	26066	359	47460
362	47990	364	47368	367	42316	369	33636	372	33384	374	42431	377	37936	379	38388	382	46639	384	37342	387	26807	389	48567
392	49211	394	48611	397	43410	399	34504	402	34334	404	43556	407	38978	409	39398	412	47858	414	38241	417	27514	419	49637
422	50388	424	49806	427	44441	429	35358	432	35255	434	44634	437	40000	439	40398	442	49028	444	39126	447	28187	449	50687
452	51519	454	50959	457	45455	459	36180	462	36149	464	45680	467	40974	469	41387	472	50146	474	40017	477	28852	479	51730

Notes:

-In all M<sub>f</sub> tables, zero (0) is equivalent to non-detectable (ND)

Air-Permeable SARATOGA™ Hammer Suit vs. HD Liquid (10g/m<sup>2</sup>)  
 Test 1  
 Modified Convective Permeation Test at 90 °F and 35% RH, 07/17/03



**Table D-9. Individual Swatch Measurements for HD, Test 1**

Swatch #	Description	Average Thickness (Inches)	Permeation Cell#	Computer Average Flow (ccm)	Pressure Difference (in WC)
1	Thigh	0.044	6	412	0.104
2	Thigh	0.044	4	440	0.100
3	Thigh	0.045	8	429	0.096
4	Chest	0.044	2	243	0.110
5	Chest	0.044	1	243	0.107
6	Chest	0.044	12	272	0.105
7	Crotch - no seam	0.044	5	430	0.101
8	Crotch - seam	0.108	9	279	0.113
9	Crotch - seam	0.089	10	399	0.092
10	Hood - seam	0.081	3	249	0.111
11	Hood - seam	0.066	11	242	0.115
12	Hood - seam	0.073	7	261	0.110

**Notes:**

- Swatches consisted of a single layer of fabric and a layer of carbon material.
- Agent beaded up on the surface of the swatch.

1-<sup>15</sup>/<sub>16</sub>-in. swatch

Used MINICAMST™ GC/FPD

Min. Detection Limit = 0.57 ng

Total Test Time = 7:57:47

Average Chamber Temperature = 32.2 °C (90.0 °F)

Average Manifold Temperature = 32.1 °C (89.8 °F)

Average Relative Humidity = 34.1%

Average Computer Flow Rate = 325 ccm

Average Pressure Difference = 0.105 in. WC

Air-Permeable SARATOGA™ Hammer Suit vs. HD Liquid (10g/m<sup>2</sup>)  
Test 1

Modified Convective Permeation Test at 90 °F and 35% RH, 07/17/03

**Table D-10. Individual M<sub>f</sub> Swatch Values at Sampling Times for HD, Test 1**

Time (min)	S #1	Time (min)	S #2	Time (min)	S #3	Time (min)	S #4	Time (min)	S #5	Time (min)	S #6	Time (min)	S #7	Time (min)	S #8	Time (min)	S #9	Time (min)	S #10	Time (min)	S #11	Time (min)	S #12
1	3	4	9	7	23	10	11	13	18	16	26	19	146	22	159	25	460	28	387	31	513	34	741
37	1013	40	767	43	793	46	334	49	302	52	338	55	1091	58	989	61	2065	65	1569	68	1771	71	2292
74	2937	77	2206	80	2183	83	958	86	824	89	897	92	2529	95	2039	98	3669	101	2746	104	2858	107	3513
110	4664	113	3609	116	3595	119	1599	122	1364	125	1484	128	4016	131	2825	134	4783	137	3559	140	3563	143	4269
146	6042	149	4832	152	4915	155	2176	158	1847	161	2018	164	5429	167	3371	170	5636	173	4159	176	4089	179	4845
182	7417	185	6011	188	6124	191	2714	194	2290	197	2523	200	6743	203	3820	206	6385	209	4683	212	4556	215	5386
218	8783	221	7120	224	7071	227	3188	230	2703	233	3037	236	7758	239	4183	242	6972	246	5114	249	4960	252	5886
255	9756	258	7979	261	7692	264	3536	267	3047	270	3543	273	8440	276	4448	279	7332	282	5399	285	5262	288	6235
291	10291	294	8639	297	8115	300	3790	303	3282	306	3982	309	8947	312	4649	315	7549	318	5562	321	5495	324	6437
327	10639	330	9123	333	8424	336	4051	339	3455	342	4294	345	9337	348	4805	351	7703	354	5663	357	5729	360	6590
363	10910	366	9417	369	8644	372	4370	375	3618	378	4500	381	9623	384	4915	387	7817	390	5736	393	5986	396	6726
399	11136	402	9630	405	8822	408	4636	411	3747	414	4647	417	9822	420	4986	423	7903	427	5792	430	6243	433	6849
436	11334	439	9806	442	8973	445	4784	448	3833	451	4755	454	9972	457	5041	460	7970	463	5836	466	6429	469	6942
472	11496	475	9951	478	9101																		

**Notes:**

-In all M<sub>f</sub> tables, zero (0) is equivalent to non-detectable (ND).

Air-Permeable SARATOGA™ Hammer Suit vs. HD Liquid (10g/m<sup>2</sup>)  
 Test 2  
 Modified Convective Permeation Test at 90 °F and 35% RH, 07/18/03

**Table D-11. Individual Swatch Measurements for HD, Test 2**

Swatch #	Description	Average Thickness (inches)	Permeation Cell#	Computer Average Flow (ccm)	Pressure Difference, inch WC
1	Upper Arm Seam	0.074	5	201	0.103
2	Upper Arm Seam	0.082	12	245	0.103
3	Upper Arm Seam	0.102	9	239	0.116
4	Lower Leg Seam	0.077	4	334	0.105
5	Lower Leg Seam	0.076	3	320	0.108
6	Lower Leg Seam	0.074	8	383	0.106

**Notes:**

- Swatches consisted of a single layer of fabric and a layer of carbon material, except for swatch #3. One half of swatch #3 was two-layer fabric with the seam as the division.
- Agent beaded up on the surface of the swatch.

1-<sup>15</sup>/<sub>16</sub>-in. swatch  
 Used MINICAMS™ GC/FPD  
 Min. Detection Limit = 0.57ng  
 Total Test Time = 7:59:37

Average Chamber Temperature = 32.0 °C (89.6 °F)  
 Average Manifold Temperature = 31.8 °C (89.2 °F)  
 Average Relative Humidity = 35.7%  
 Average Computer Flow Rate = 287ccm  
 Average Pressure Difference = 0.107 in. WC

**Air-Permeable SARATOGA™ Hammer Suit vs. HD Liquid (10g/m<sup>2</sup>)**

**Test 2**

**Modified Convective Permeation Test at 90 °F and 35% RH, 07/18/03**

**Table D-12. Individual M<sub>f</sub> Swatch Values at Sampling Times for HD, Test 2**

Time (min)	S #1	Time (min)	S #2	Time (min)	S #3	Time (min)	S #4	Time (min)	S #5	Time (min)	S #6
3	2	6	7	9	7	12	34	15	137	18	350
21	167	24	173	27	100	30	286	33	689	36	1285
39	547	42	529	45	307	48	773	51	1522	54	2460
57	1024	60	966	63	579	66	1359	69	2362	72	3515
75	1505	78	1395	81	862	84	1948	87	3079	90	4330
93	1950	97	1770	100	1125	103	2511	106	3675	109	4961
112	2348	115	2081	118	1366	121	3044	124	4184	127	5484
130	2686	133	2336	136	1587	139	3538	142	4631	145	5937
148	2966	151	2545	154	1790	157	3974	160	5027	163	6335
166	3192	169	2715	172	1978	175	4352	178	5374	181	6691
184	3381	187	2863	190	2155	193	4690	196	5690	199	7010
202	3544	205	2996	208	2325	211	5000	214	5986	217	7308
220	3692	223	3116	226	2490	229	5293	232	6264	235	7587
238	3828	241	3228	244	2649	247	5570	250	6532	253	7845
256	3956	259	3334	262	2805	265	5842	268	6791	271	8085
274	4075	278	3435	281	2958	284	6114	287	7043	290	8305
293	4188	296	3527	299	3106	302	6372	305	7285	308	8509
311	4296	314	3614	317	3249	320	6595	323	7503	326	8698
329	4397	332	3693	335	3386	338	6782	341	7695	344	8869
347	4489	350	3765	353	3511	356	6944	359	7863	362	9020
365	4574	368	3827	371	3625	374	7084	377	8005	380	9153
383	4650	386	3881	389	3725	392	7205	395	8124	398	9270
401	4718	404	3927	407	3809	410	7306	413	8218	416	9363
419	4776	422	3967	425	3878	428	7386	431	8291	434	9435
437	4828	440	4000	443	3933	446	7451	449	8348	452	9493
455	4873	459	4028	462	3976	465	7503	468	8396	471	9542
474	4909	477	4052	480	4009						

**Notes:**

-In all M<sub>f</sub> tables, zero (0) is equivalent to non-detectable (ND).

# **Air-Permeable SARATOGA™ Hammer Suit vs. GB Liquid (10g/m<sup>2</sup>)**

## **Test 1**

**Modified Convective Permeation Test at 90 °F and 35% RH, 07/23/03**

**Table D-13. Individual Swatch Measurements for GB, Test 1**

Swatch #	Description	Average Thickness (Inches)	Permeation Cell#	Computer Average Flow (ccm)	Pressure Difference (Inch WC)
1	Thigh	0.045	3	376	0.099
2	Thigh	0.045	1	495	0.100
3	Thigh	0.045	11	429	0.101
4	Chest	0.044	8	233	0.105
5	Chest	0.044	7	210	0.101
6	Chest	0.045	2	237	0.102
8	Hood-Seam	0.071	10	174	0.102
9	Hood-Seam	0.062	6	249	0.099
10	Crotch-Seam	0.114	4	299	0.105
12	Crotch-No Seam	0.045	5	452	0.101

### Notes:

-Swatches consisted of a single layer of fabric and a layer of carbon material, except for both of the crotch-seam swatches. They had two layers of fabric on approximately half of the swatch. The seam was the division of one or two layers of fabric. Swatches #7 and 11 were not tested due to flow errors. Swatch #7 was a hood-seam; swatch #11 was a crotch-seam. These were tested at another time.

-Agent beaded up on the surface of the swatches.

1-<sup>15</sup>/<sub>16</sub>-in. swatch

Used MINICAMS™ GC/FPD

Min. Detection Limit = 0.57 ng

Total Test Time = 7:58:42

Average Chamber Temperature = 32.1 °C (89.8 °F)

Average Manifold Temperature = 31.8 °C (89.2 °F)

Average Relative Humidity = 35.6%

Average Computer Flow Rate = 315 ccm

Average Pressure Difference = 0.102 in. WC



# Air-Permeable SARATOGA™ Hammer Suit vs. GB Liquid (10g/m<sup>2</sup>)

## Test 1

### Modified Convective Permeation Test at 90 °F and 35% RH, 07/23/03

**Table D-14. Individual M<sub>r</sub> Swatch Values at Sampling Times for GB, Test 1**

Time (min)	S #1	Time (min)	S #2	Time (min)	S #3	Time (min)	S #4	Time (min)	S #5	Time (min)	S #6	Time (min)	S #8	Time (min)	S #9	Time (min)	S #10	Time (min)	S #12
1	0	3	1223	6	1836	8	694	11	626	13	819	18	4918	21	8057	23	7340	28	5199
31	4321	33	17439	36	15163	38	4712	41	3730	43	4185	48	15678	51	24908	53	19990	58	11735
61	9716	63	24401	66	20508	68	6897	71	5744	73	6502	78	19361	81	32107	83	24377	88	13429
91	11656	93	27710	96	23126	98	8072	101	6894	103	7903	108	20961	111	35231	113	26317	118	14576
121	13172	123	30208	126	25120	128	8965	131	7777	134	9009	139	22052	141	37234	144	27661	149	15541
151	14485	154	32344	156	26816	159	9728	161	8509	164	9977	169	22913	171	38734	174	28694	179	16418
181	15699	184	34230	186	28323	189	10417	191	9190	194	10854	199	23639	201	39971	204	29558	209	17199
211	16805	214	35920	216	29709	219	11036	221	9812	224	11636	229	24283	231	41024	234	30299	239	17937
241	17798	244	37430	246	30971	249	11597	251	10400	254	12344	259	24879	261	41979	264	30992	269	18632
271	18743	274	38839	276	32144	279	12129	281	10957	284	13026	289	25424	291	42871	294	31646	299	19281
301	19661	304	40216	306	33259	309	12635	311	11472	314	13680	319	25929	321	43693	324	32242	329	19909
331	20545	334	41503	336	34308	339	13112	341	11965	344	14305	349	26401	351	44460	354	32799	359	20504
361	21398	364	42761	366	35309	369	13561	371	12436	374	14909	379	26858	381	45185	384	33338	389	21092
391	22241	394	43976	396	36270	399	13992	401	12893	404	15474	409	27296	411	45874	414	33851	419	21680
421	23078	424	45107	426	37203	429	14415	431	13337	434	16017	439	27710	441	46535	444	34329	449	22229
451	23862	454	46198	456	38099	459	14815	461	13772	464	16535	469	28106	471	47165	474	34767	479	22749

#### Notes:

-In all M<sub>r</sub> tables, zero (0) is equivalent to non-detectable (ND).



Air-Permeable SARATOGA™ Hammer Suit vs. GB Liquid (10g/m<sup>2</sup>)  
 Test 2  
 Modified Convective Permeation Test at 90 °F and 35% RH, 07/24/03

**Table D-15. Individual Swatch Measurements for GB, Test 2**

Swatch #	Description	Average Thickness (inches)	Permeation Cell#	Computer Average Flow (ccm)	Pressure Difference (inch WC)
1	Upper Arm Seam	0.072	11	221	0.102
2	Upper Arm Seam	0.083	2	280	0.102
3	Upper Arm Seam	0.084	5	269	0.104
4	Upper Leg Seam	0.075	6	414	0.107
5	Upper Leg Seam	0.105	10	240	0.102
6	Upper Leg Seam	0.111	4	333	0.101
7	Hood-Seam	0.067	9	251	0.108
8	Crotch-Seam	0.116	12	424	0.099

**Notes:**

-Swatches consisted of a single layer of fabric and a layer of carbon material, except for swatches #3, 5, 6, and 8. About one half of swatches #5, 6, and 8 have two layers of fabric, with the seam as the division. A very small portion of swatch #3 has two layers of fabric.

-Agent beaded up on the surface of the swatch.

1-<sup>15</sup>/<sub>16</sub>-in. swatch

Used MINICAMS™ GC/FPD

Min. Detection Limit = 0.57ng

Total Test Time = 7:57:46

Average Chamber Temperature = 32.0 °C (89.6 °F)

Average Manifold Temperature = 31.7 °C (89.1 °F)

Average Relative Humidity = 35.2%

Average Computer Flow Rate = 304 ccm

Average Pressure Difference = 0.103 in. WC

# **Air-Permeable SARATOGA™ Hammer Suit vs. GB Liquid (10g/m<sup>2</sup>)**

## **Test 2**

**Modified Convective Permeation Test at 90 °F and 35% RH, 07/24/03**

**Table D-16. Individual M<sub>f</sub> Swatch Values at Sampling Times for GB, Test 2**

Time (min)	S #1	Time (min)	S #2	Time (min)	S #3	Time (min)	S #4	Time (min)	S #5	Time (min)	S #6	Time (min)	S #7	Time (min)	S #8
2	394	5	981	7	1042	10	1354	12	2218	15	4091	18	3450	20	1844
23	6651	25	8576	28	6418	30	5855	33	8011	35	12649	38	10590	40	4618
43	11370	45	14383	48	10631	50	8431	53	11231	55	16969	58	15794	60	5929
63	14140	65	18143	68	13352	70	9652	73	12772	75	18904	78	19003	80	6553
83	15889	85	20598	88	15116	90	10372	93	13699	95	20096	98	20909	100	6955
103	17086	105	22166	108	16280	110	10891	113	14356	115	20928	118	22155	120	7236
123	18003	125	23426	128	17140	130	11302	133	14880	135	21588	138	23140	140	7458
143	18723	145	24413	148	17807	150	11642	153	15325	155	22142	158	23953	160	7645
163	19325	165	25221	168	18346	170	11938	173	15723	175	22618	178	24619	180	7812
183	19856	185	25936	188	18832	190	12205	193	16082	195	23063	198	25194	200	7959
203	20328	205	26577	208	19260	210	12453	213	16394	215	23469	218	25693	220	8091
223	20748	225	27168	228	19627	230	12679	233	16681	235	23836	238	26128	240	8210
243	21143	245	27676	248	19953	250	12887	253	16959	255	24174	258	26523	260	8322
263	21511	265	28144	268	20243	270	13084	273	17224	275	24490	278	26885	280	8428
283	21843	285	28587	288	20515	290	13265	293	17467	295	24791	298	27231	300	8528
303	22160	305	28994	308	20768	310	13435	313	17694	315	25074	318	27554	320	8624
323	22458	325	29371	328	20998	330	13600	333	17913	335	25350	338	27867	340	8714
343	22734	345	29728	348	21215	350	13759	353	18122	355	25619	358	28167	360	8801
363	23009	365	30075	368	21421	370	13912	373	18324	375	25868	378	28442	380	8885
383	23273	385	30403	388	21620	390	14061	393	18516	395	26104	398	28707	400	8966
403	23517	405	30711	408	21812	410	14208	413	18699	415	26335	418	28965	420	9043
423	23756	425	31015	428	21997	430	14350	433	18883	435	26560	438	29218	440	9119
443	23993	445	31320	448	22173	450	14484	453	19063	455	26780	458	29462	460	9193
463	24218	465	31609	468	22340	470	14615	473	19237	475	26999	478	29697		

### **Notes:**

-In all M<sub>f</sub> tables, zero (0) is equivalent to non-detectable (ND).

**APPENDIX E**  
**PROTECTION FACTOR TEST DATA**

Table E. Aerosol Protection Factor Test Data

DATE	TIME	MASK	SUBJECT	TRIAL	ITEM	PF <sub>0</sub>	EXRCS1	EXRCS2	EXRCS3	EXRCS4	EXRCS5	EXRCS6	EXRCS7	EXRCS8
8/16/2003	09:17:06	M1	1	1	SUIT 5	2.40	2.12	2.00	2.84	2.53	2.36	2.79	2.70	2.14
8/16/2003	09:35:02	M1	1	2	SUIT 5	2.59	2.55	2.48	3.46	2.57	2.45	2.66	2.63	2.20
8/16/2003	09:17:08	M13	2	1	SUIT 7	2.46	1.98	1.96	2.76	2.75	2.62	3.07	3.30	1.99
8/16/2003	09:35:04	M13	2	2	SUIT 7	3.32	3.13	2.80	4.08	3.90	3.02	3.21	3.75	3.13
8/16/2003	09:17:09	M2	3	1	SUIT 6	2.52	1.95	2.25	3.06	2.77	2.24	3.45	3.89	1.86
8/16/2003	09:35:05	M2	3	2	SUIT 6	2.61	2.71	2.18	3.11	3.03	2.39	2.78	3.09	2.08
8/16/2003	09:17:10	M11	4	1	SUIT 8	1.88	1.69	1.85	2.03	2.03	1.70	2.04	2.09	1.71
8/16/2003	09:35:06	M11	4	2	SUIT 8	2.18	1.93	2.12	3.00	2.41	2.13	2.56	1.88	1.86
8/16/2003	10:04:23	M14	5	1	SUIT 1	2.11	1.92	2.04	2.35	2.20	1.79	2.55	2.34	1.89
8/16/2003	10:22:22	M14	5	2	SUIT 1	2.30	2.14	2.12	2.70	2.47	2.20	2.63	2.30	2.00
8/16/2003	10:04:24	S1	6	1	SUIT 2	2.42	1.93	2.47	2.85	2.77	2.15	3.06	2.59	2.03
8/16/2003	10:22:23	S1	6	2	SUIT 2	2.20	2.10	2.21	2.43	2.54	2.01	2.74	2.32	1.66
8/16/2003	10:04:25	S4	7	1	SUIT 3	2.27	1.89	2.25	2.85	2.64	2.28	2.51	2.10	2.01
8/16/2003	10:22:24	S4	7	2	SUIT 3	2.60	2.53	2.47	3.22	3.15	2.61	2.63	2.49	2.09
8/16/2003	10:04:26	M8	8	1	SUIT 4	2.11	1.75	2.10	2.61	2.42	2.15	2.10	2.08	1.90
8/16/2003	10:22:26	M8	8	2	SUIT 4	1.98	2.19	1.77	2.35	2.18	1.81	2.06	1.96	1.73
8/16/2003	10:00:29	M13	9	1	SUIT 5	2.70	2.65	2.40	3.55	2.64	2.67	2.91	3.13	2.14
8/16/2003	10:18:48	M13	9	2	SUIT 5	3.29	3.21	2.85	4.93	3.33	3.25	3.49	3.26	2.72
8/16/2003	10:00:30	M14	10	1	SUIT 7	3.12	3.02	2.82	3.55	3.12	3.02	3.91	3.36	2.54
8/16/2003	10:18:49	M14	10	2	SUIT 7	2.81	3.05	2.59	3.92	2.68	2.56	3.26	2.46	2.47
8/16/2003	10:00:31	S1	11	1	SUIT 6	3.02	2.88	2.61	4.29	3.22	2.34	3.17	3.34	3.01
8/16/2003	10:18:50	S1	11	2	SUIT 6	2.97	3.26	2.26	3.91	3.13	2.64	3.13	3.28	2.71
8/16/2003	10:00:32	M2	12	1	SUIT 8	2.77	2.45	2.36	3.70	2.93	3.05	3.21	2.74	2.27
8/16/2003	10:18:51	M2	12	2	SUIT 8	2.51	2.18	2.09	3.23	2.68	2.66	2.62	2.56	2.40
8/16/2003	10:47:29	M11	13	1	SUIT 1	2.04	2.69	2.15	2.40	2.08	1.97	2.03	1.86	1.53
8/16/2003	11:06:09	M11	13	2	SUIT 1	2.48	2.70	2.49	2.89	3.11	2.26	2.83	2.32	1.80
8/16/2003	10:47:30	M1	14	1	SUIT 2	2.38	2.49	2.62	2.50	2.66	2.16	2.33	2.44	2.00
8/16/2003	11:06:10	M1	14	2	SUIT 2	2.93	2.95	2.73	3.65	3.01	2.64	3.11	3.32	2.40
8/16/2003	10:47:31	S4	15	1	SUIT 3	2.92	3.38	3.15	3.85	3.16	2.54	2.59	2.78	2.45
8/16/2003	11:06:11	S4	15	2	SUIT 3	3.41	4.83	3.30	4.26	3.26	2.97	3.13	3.83	2.65
8/16/2003	10:47:32	M8	16	1	SUIT 4	3.06	2.41	2.67	4.07	3.56	2.71	3.53	3.28	2.93
8/16/2003	11:06:12	M8	16	2	SUIT 4	2.86	2.81	2.40	3.71	3.50	3.09	3.08	2.67	2.22